CLAIMS

What is claimed is:

1. A method for analyzing an object image with respect to a model pattern, the method comprising:

extracting pattern features from the model pattern;

generating a vector-valued function using the pattern features to provide a pattern field;

extracting image features from the object image;

evaluating each image feature, using the pattern field and an n-dimensional transformation that associates image features with pattern features, so as to determine at least one associated feature characteristic of the image; and

using at least one feature characteristic to identify at least one flaw in the object image.

2. The method of claim 1, wherein at least one associated feature characteristic includes a probability value indicating the likelihood that an associated image feature does not correspond to a feature in the model pattern.

3. The method of claim 1, wherein at least one associated feature characteristic includes a probability value indicating the likelihood that an associated image feature does correspond to a feature in the model pattern.

4. The method of claim 1, wherein at least one pattern feature includes a probability value indicating the likelihood that the pattern feature does not correspond to at least one feature in the object image.

5. The method of claim 1, wherein using at least one feature characteristic includes transferring a feature characteristic from the at least one image feature to an element of the pattern field.

6. The method of claim 5, wherein the element of the pattern field is the nearest element of the pattern field.

7. The method of claim 1, wherein using at least one feature characteristic comprises:

using a plurality of image features; and

transferring a plurality of the feature characteristics from the plurality of image features to a plurality of elements of the pattern field.

8. The method of claim 7, wherein some of the plurality of elements of the pattern field includes at least one link to a neighboring element of the pattern field.

9. The method of claim 8, further including:

after transferring a plurality of the feature characteristics from the plurality of image features to a plurality of elements of the pattern field, each element of the plurality of elements of the pattern field receives an feature characteristic equal to the maximum of their own feature characteristic and the feature characteristic of each neighboring element of the pattern field.

10. The method of claim 1, wherein using at least one feature characteristic includes:

identifying the nearest element of the pattern field;

transferring a feature characteristic from the at least one image feature to the nearest element of the pattern field; and

computing a coverage value using at least the transferred feature characteristic.

11. The method of claim 1, wherein evaluating each image feature includes comparing the direction of each image feature with the direction of an element of the pattern field.

12. The method of claim 11, wherein a higher weight is assigned to the image feature if the difference in the direction of the image feature from the direction of an element of the pattern field is less than a specified direction parameter.

13. The method of claim 12, wherein the specified direction parameter is determined by a characteristic of the element of the pattern field.

14. The method of claim 11, wherein a lower weight is assigned to the image feature if the difference in the direction of the image feature from the direction of an element of the pattern field is greater than a specified direction parameter.

15. The method of claim 14, wherein the specified direction parameter is determined by a characteristic of the element of the pattern field.

16. The method of claim 1, wherein evaluating each image feature includes comparing, modulo 180 degrees, the direction of each image feature with the direction of an element of the pattern field.

17. The method of claim 1, wherein evaluating each image feature includes assigning a weight of zero when the image feature is at a position that corresponds to an element of the pattern field that specified that no image feature is expected at that position.

18. The method of claim 1, wherein evaluating each image feature includes comparing the distance of each image feature with a specified distance parameter.

19. The method of claim 18, wherein a lower weight is assigned to the image feature if the distance of the image feature is greater than a specified distance parameter.

20. The method of claim 18, wherein a higher weight is assigned to the image feature if the distance of the image feature is less than a specified distance parameter.

21. The method of claim 1, wherein evaluating each image feature includes comparing the direction of each image feature with the direction of an element of the pattern field, and comparing the distance of each image feature with a specified distance parameter.

22. The method of claim 1, wherein extracting pattern features from the model pattern includes extracting a plurality of pattern positions.

23. The method of claim 1, wherein extracting pattern features from the model pattern includes extracting a plurality of pattern positions and associated directions.

24. The method of claim 1, wherein extracting pattern features from the model pattern includes extracting a plurality of pattern positions and associated directions and weights.

25. The method of claim 1, wherein extracting image features from the object image includes extracting a plurality of image positions.

26. The method of claim 1, wherein extracting image features from the object image includes extracting a plurality of image positions and associated directions.

27. The method of claim 1, wherein extracting image features from the object image includes extracting a plurality of image positions and associated directions and weights.

28. The method of claim 1, wherein the vector-valued function relates a plurality of at least two-dimensional positions to a plurality of respective displacement vectors.

29. The method of claim 1, wherein the vector-valued function relates a plurality of two-dimensional positions and associated directions to a plurality of respective displacement vectors.

30. The method of claim 28, wherein each displacement vector indicates a distance and a direction from a two-dimensional position to a nearest point along the pattern boundary.

31. The method of claim 29, wherein each displacement vector indicates distance and a direction from a two-dimensional position to a nearest point along a pattern boundary that is substantially in the associated direction.

32. The method of claim 1, wherein dimensions of the n-dimensional transformation includes horizontal position and vertical position.

33. The method of claim 1, wherein dimensions of the n-dimensional transformation includes horizontal position, vertical position, and orientation.

34. The method of claim 1, wherein dimensions of the n-dimensional transformation includes horizontal position, vertical position, and size.

35. The method of claim 1, wherein dimensions of the n-dimensional transformation includes horizontal position, vertical position, orientation, and size.

36. The method of claim 26, wherein each associated direction is a gradient direction.

37. The method of claim 26, wherein each associated direction is a direction generally normal to the pattern boundary at the boundary position.

38. The method of claim 1, wherein generating a vector-valued function includes a sequence of propagation events, each propagation event providing additional vectors of the vector-valued function.

39. The method of claim 1, wherein the model pattern is a trained image.

40. The method of claim 1, wherein the model pattern is a geometric description.

41. The method of claim 1, wherein the object image is instead a geometric description.

42. The method of claim 1, wherein the n-dimensional transformation is obtained using normalized correlation search.

43. The method of claim 1, wherein the n-dimensional transformation is obtained using a generalized Hough transform.

44. The method of claim 1, wherein the n-dimensional transformation is obtained by a user with a pointing device.

45. The method of claim 1, wherein the n-dimensional transformation is the best of a sequence of incrementally better n-dimensional transformations.

46. The method of claim 45, wherein the sequence of incrementally better n-dimensional transformations is obtained using an error minimization technique.

47. The method of claim 46, wherein the error minimization technique includes least squares fitting.

48. An apparatus for analyzing an object image with respect to a model pattern, the apparatus comprising:

an extractor of pattern features from the model pattern;

a generator of a vector-valued function using the pattern features to provide a pattern field;

an extractor of image features from the object image;

an evaluator of each image feature, the evaluator using the pattern field and an n-dimensional transformation that associates image features with pattern features, the evaluator determining at least one associated feature characteristic; and

a flaw identifier that uses at least one feature characteristic to identify at least one flaw in the object image.

49. The apparatus of claim 48, wherein at least one associated feature characteristic includes a probability value indicating the likelihood that an associated image feature does not correspond to a feature in the model pattern.

50. The apparatus of claim 48, wherein at least one associated feature characteristic includes a probability value indicating the likelihood that an associated image feature does correspond to a feature in the model pattern.

51. The apparatus of claim 48, wherein at least one pattern feature includes a probability value indicating the likelihood that the pattern feature does not correspond to at least one feature in the object image.

52. The apparatus of claim 48, wherein the flaw identifier transfers an feature characteristic from the at least one image feature to an element of the pattern field.

53. The apparatus of claim 52, wherein the element of the pattern field is the nearest element of the pattern field.

54. The apparatus of claim 48, wherein the flaw identifier uses a plurality of image features; and transfers a plurality of the feature characteristics from the plurality of image features to a plurality of elements of the pattern field.

55. The apparatus of claim 54, wherein some of the plurality of elements of the pattern field includes at least one link to a neighboring element of the pattern field.

56. The apparatus of claim 55, further including:
after transferring a plurality of the feature characteristics from the plurality of image features to a plurality of elements of the pattern field, each element of the plurality of elements of the pattern field receives a feature characteristic equal to the maximum of their own feature characteristic and the feature characteristic of each neighboring element of the pattern field.

57. The apparatus of claim 48, wherein the flaw identifier identifies the nearest element of the pattern field, transfers a feature characteristic from the at least one image feature to the nearest element of the pattern field; and computes a coverage value using at least the transferred feature characteristic.

58. The apparatus of claim 48, wherein the evaluator of each image feature compares the direction of each image feature with the direction of an element of the pattern field.

59. The apparatus of claim 58, wherein a higher weight is assigned to the image feature if the difference in the direction of the image feature from the direction of an element of the pattern field is less than a specified direction parameter.

60. The apparatus of claim 59, wherein the specified direction parameter is determined by a characteristic of the element of the pattern field.

61. The apparatus of claim 58, wherein a lower weight is assigned to the image feature if the difference in the direction of the image feature from the direction of an element of the pattern field is greater than a specified direction parameter.

62. The apparatus of claim 61, wherein the specified direction parameter is determined by a characteristic of the element of the pattern field.

63. The apparatus of claim 48, wherein the evaluator of each image feature compares, modulo 180 degrees, the direction of each image feature with the direction of an element of the pattern field.

64. The apparatus of claim 48, wherein the evaluator of each image feature assigns a weight of zero when the image feature is at a position that corresponds to an element of the pattern field that specified that no image feature is expected at that position.

65. The apparatus of claim 48, wherein the evaluator of each image feature compares the distance of each image feature with a specified distance parameter.

66. The apparatus of claim 65, wherein a lower weight is assigned to the image feature if the distance of the image feature is greater than a specified distance parameter.

67. The apparatus of claim 65, wherein a higher weight is assigned to the image feature if the distance of the image feature is less than a specified distance parameter.

68. The apparatus of claim 48, wherein the evaluator of each image feature compares the direction of each image feature with the direction of an element of the pattern field, and compares the distance of each image feature with a specified distance parameter.

69. The apparatus of claim 48, wherein the extractor of pattern features from the model pattern extracts a plurality of pattern positions.

70. The apparatus of claim 48, wherein the extractor of pattern features from the model pattern extracts a plurality of pattern positions and associated directions.

71. The apparatus of claim 48, wherein the extractor of pattern features from the model pattern extracts a plurality of pattern positions and associated directions and weights.

72. The apparatus of claim 48, wherein the extractor of image features from the object image extracts a plurality of image positions.

73. The apparatus of claim 48, wherein the extractor of image features from the object image extracts a plurality of image positions and associated directions.

74. The apparatus of claim 48, wherein the extractor of image features from the object image extracts a plurality of image positions and associated directions and weights.

75. Computer software, residing on a computer-readable storage medium, comprising instructions for use in a computer system to analyze an object image with respect to a model pattern, the instructions causing the system to:

extract pattern features from the model pattern;

generate a vector-valued function using the pattern features to provide a pattern field;

extract image features from the object image;

evaluate each image feature, using the pattern field and an n-dimensional transformation that associates image features with pattern features, so as to determine at least one associated feature characteristic; and

identify at least one flaw in the object image, using at least one feature characteristic.

76. The software of claim 75, wherein at least one associated feature characteristic includes a probability value indicating the likelihood that an associated image feature does not correspond to a feature in the model pattern.

77. The software of claim 75, wherein at least one associated feature characteristic includes a probability value indicating the likelihood that an associated image feature does correspond to a feature in the model pattern.

78. The software of claim 75, wherein at least one pattern feature includes a probability value indicating the likelihood that the pattern feature does not correspond to at least one feature in the object image.

79. The software of claim 75, wherein to use at least one feature characteristic includes transferring a feature characteristic from the at least one image feature to an element of the pattern field.

80. The software of claim 79, wherein the element of the pattern field is the nearest element of the pattern field.

81. The software of claim 75, wherein to use at least one feature characteristic comprises:
using a plurality of image features; and
transferring a plurality of the feature characteristics from the plurality of image features to a plurality of elements of the pattern field.

82. The software of claim 81, wherein some of the plurality of elements of the pattern field includes at least one link to a neighboring element of the pattern field.

83. The software of claim 8, wherein:

after transferring a plurality of the feature characteristics from the plurality of image features to a plurality of elements of the pattern field, each element of the plurality of elements of the pattern field receives a feature characteristic equal to the maximum of their own feature characteristic and the feature characteristic of each neighboring element of the pattern field.

84. The software of claim 75, wherein to use at least one feature characteristic includes:

identifying the nearest element of the pattern field;

transferring a feature characteristic from the at least one image feature to the nearest element of the pattern field; and

computing a coverage value using at least the transferred feature characteristic.

85. The software of claim 75, wherein to evaluate each image feature includes comparing the direction of each image feature with the direction of an element of the pattern field.

86. The software of claim 85, wherein a higher weight is assigned to the image feature if the difference in the direction of the image feature from the direction of an element of the pattern field is less than a specified direction parameter.

87. The software of claim 86, wherein the specified direction parameter is determined by a characteristic of the element of the pattern field.

88. The software of claim 85, wherein a lower weight is assigned to the image feature if the difference in the direction of the image feature from the direction of an element of the pattern field is greater than a specified direction parameter.

89. The software of claim 88, wherein the specified direction parameter is determined by a characteristic of the element of the pattern field.

90. The software of claim 75, wherein to evaluate each image feature includes comparing, modulo 180 degrees, the direction of each image feature with the direction of an element of the pattern field.

91. The software of claim 75, wherein to evaluate each image feature includes assigning a weight of zero when the image feature is at a position that corresponds to an element of the pattern field that specified that no image feature is expected at that position.

92. The software of claim 75, wherein to evaluate each image feature includes comparing the distance of each image feature with a specified distance parameter.

93. The software of claim 92, wherein a lower weight is assigned to the image feature if the distance of the image feature is greater than a specified distance parameter.

94. The software of claim 92, wherein a higher weight is assigned to the image feature if the distance of the image feature is less than a specified distance parameter.

95. The software of claim 75, wherein to evaluate each image feature includes comparing the direction of each image feature with the direction of an element of the pattern field, and comparing the distance of each image feature with a specified distance parameter.

96. The software of claim 75, wherein to extract pattern features from the model pattern includes extracting a plurality of pattern positions.

97. The software of claim 75, wherein to extract pattern features from the model pattern includes extracting a plurality of pattern positions and associated directions.

98. The software of claim 75, wherein to extract pattern features from the model pattern includes extracting a plurality of pattern positions and associated directions and weights.

99. The software of claim 75, wherein to extract image features from the object image includes extracting a plurality of image positions.

100. The software of claim 75, wherein extracting image features from the object image includes extracting a plurality of image positions and associated directions.

101. The software of claim 75, wherein extracting image features from the object image includes extracting a plurality of image positions and associated directions and weights.

102. The software of claim 75, wherein the vector-valued function relates a plurality of at least two-dimensional positions to a plurality of respective displacement vectors.

103. The software of claim 75, wherein the vector-valued function relates a plurality of two-dimensional positions and associated directions to a plurality of respective displacement vectors.

104. The software of claim 102, wherein each displacement vector indicates a distance and a direction from a two-dimensional position to a nearest point along the pattern boundary.

105. The software of claim 103, wherein each displacement vector indicates distance and a direction from a two-dimensional position to a nearest point along a pattern boundary that is substantially in the associated direction.

106. The software of claim 75, wherein dimensions of the n-dimensional transformation includes horizontal position and vertical position.

107. The software of claim 75, wherein dimensions of the n-dimensional transformation includes horizontal position, vertical position, and orientation.

108. The software of claim 75, wherein dimensions of the n-dimensional transformation includes horizontal position, vertical position, and size.

109. The software of claim 75, wherein dimensions of the n-dimensional transformation includes horizontal position, vertical position, orientation, and size.

110. The software of claim 100, wherein each associated direction is a gradient direction.

111. The software of claim 100, wherein each associated direction is a direction generally normal to the pattern boundary at the boundary position.

112. The software of claim 75, wherein generating a vector-valued function includes a sequence of propagation events, each propagation event providing additional vectors of the vector-valued function.

113. The software of claim 75, wherein the model pattern is a trained image.

114. The software of claim 75, wherein the model pattern is a geometric description.

115. The software of claim 75, wherein the object image is instead a geometric description.

116. The software of claim 75, wherein the n-dimensional transformation is obtained using normalized correlation search.

117. The software of claim 75, wherein the n-dimensional transformation is obtained using a generalized Hough transform.

118. The software of claim 75, wherein the n-dimensional transformation is obtained by a user with a pointing device.

119. The software of claim 75, wherein the n-dimensional transformation is the best of a sequence of incrementally better n-dimensional transformations.

120. The software of claim 119, wherein the sequence of incrementally better n-dimensional transformations is obtained using an error minimization technique.

121. The software of claim 120, wherein the error minimization technique includes least squares fitting.